Recent Results from the JLab Spin Physics Program

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Abstract

We present here select recent results from the Thomas Jefferson National Laboratory Spin Physics program, along with the perspective on some upcoming experiments.

1 EG4: The Proton/Deuteron GDH Sum at Low Q^2

The Gerasimov-Drell-Hearn(GDH) sum rule [2] for real photon scattering from a target of arbitrary spin $\mathcal{S}$ reads:

$$\int_{\nu_{th}}^{\infty} \frac{\sigma_P(\nu) - \sigma_A(\nu)}{\nu} d\nu \;\; = \;\; -4\pi^2 \alpha \, \mathcal{S} \left(\frac{\kappa}{m}\right)^2 \qquad (1)$$

where σ_P and σ_A represent the cross section for photoabsorption with the photon helicity parallel or anti-parallel to the target spin in its maximal state. The target mass and anomalous magnetic moment are represented by m and κ respectively, and ν is the photon energy. Extending the sum rule to finite Q^2 provides a powerful tool to investigate the spin structure of the nucleon. For a hadronic target the generalization [3] can be written:

$$\overline{S_1}(0, Q^2) = \frac{8}{Q^2} \int_0^{1-\epsilon} g_1(x, Q^2) \; dx \equiv \frac{8}{Q^2} \overline{\Gamma}_1 \qquad (2)$$

Here g_1 is the spin structure function, S_1 is the forward Compton amplitude, and the overbar represents exclusion of the elastic contribution. The forward Compton amplitudes can be evaluated in Chiral Perturbation theory at low Q^2, or via the higher twist expansion at large Q^2. Lattice QCD holds the promise of eventually evaluating these moments at any Q^2.

EG4 [1] ran successfully in JLab's Hall B in early 2006. The goal was to extend our knowledge of the proton and deuteron(neutron) spin structure to the lowest possible JLab momentum transfer ($0.015 < Q^2 < 0.2$ GeV^2) in the resonance region ($W < 2$ GeV).

In order to extract g_1 we performed an absolute (polarized) cross section measurement. For this purpose, a new Čerenkov counter was built and commissioned by the INFN Genova group. This new detector was designed for high electron detection efficiency (of the order 99.9%) and a high pion rejection ratio (of the order 10^{-3}). We also utilized the JLab-UVA polarized target. This target exploits the Dynamical Nuclear Polarization (DNP) technique to polarize a solid ammonia insert maintained in a liquid helium bath at 1 K in a 5 Tesla field.

In Fig. 1, we show the expected precision for the proton and deuteron extended GDH sum, along with several theoretical predictions. The high precision data will also allow

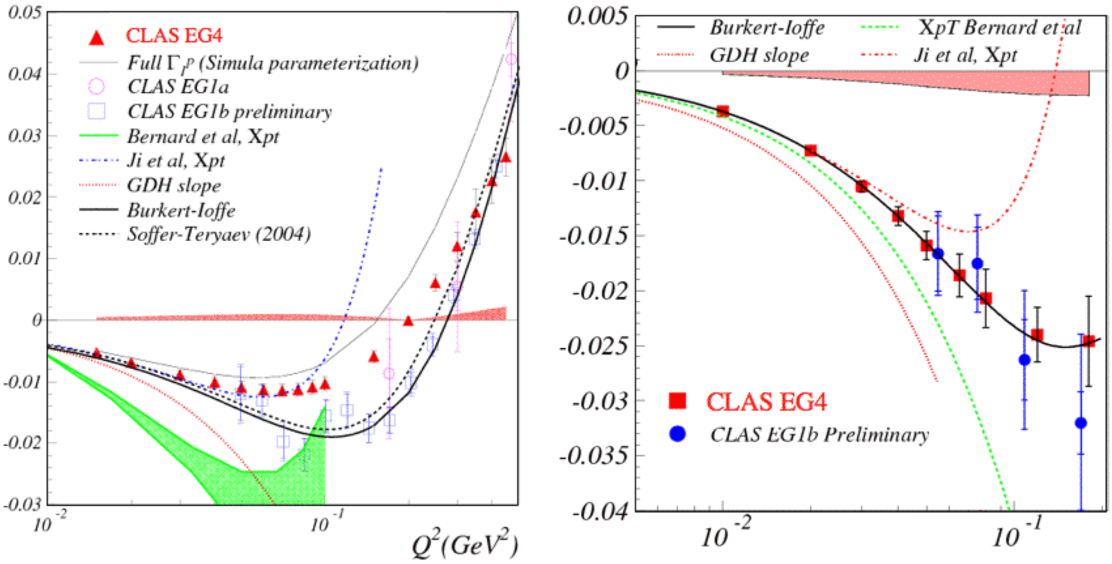

Figure 1: **Left:** Projected uncertainty of proton Γ_1. **Right:** Projected uncertainty of deuteron Γ_1. The band represents the systematic uncertainty, while the error bars on the points are statistical only. The curves from Bernard *et al.* and Ji *et al.* are χPT calculations. The curve from Burkert-Ioffe and Soffer-Teryaev are phenomenological models. The preliminary EG1B data are also shown for comparison.

an extraction of the neutron extended GDH sum. In addition to testing χPT and lattice calculations, we will indirectly test the the real photon GDH sum rule, by extrapolating to $Q^2 = 0$.

2 δ_{LT} : The Generalized LT Spin Polarizability

In recent years, Chiral Perturbation Theory (χPT) has emerged as the effective theory of QCD at low energy. It has also been used as a powerful tool to help Lattice QCD (LQCD) to extrapolate to the physical region. In light of this, it is critical to have benchmark tests of the reliability of χPT calculations. The JLab experimental program on the spin structure of the nucleon has extracted the spin structure functions g_1^n, g_2^n and g_1^p and their moments over a wide kinematic range. These moments have proven to be powerful tools to test QCD sum rules and χPT calculations. However, at the low Q^2 relevant to χPT, data on the g_2^p structure function is conspicuously absent. Currently, the lowest momentum transfer that has been investigated is $Q^2 \approx 1.3$ GeV^2 by the RSS collaboration [4].

The absence of transverse data is particularly unsatisfying given the intriguing results found in the transverse neutron data: The SLAC E155 collaboration found a three sigma violation of the proton Burkhardt-Cottingham (BC) sum rule at $Q^2 = 5.0$ GeV^2, while the JLab E94010 collaboration found that the neutron BC sum rule held below $Q^2 = 1.0$ GeV^2. Even more compelling, it was found that state-of-the-art NLO χPT calculations are in agreement with the neutron data for the generalized polarizability γ_0^n at $Q^2 = 0.1$ GeV^2, but exhibit a significant discrepancy [6] with the longitudinal-transverse polarizability δ_{LT}^n. This

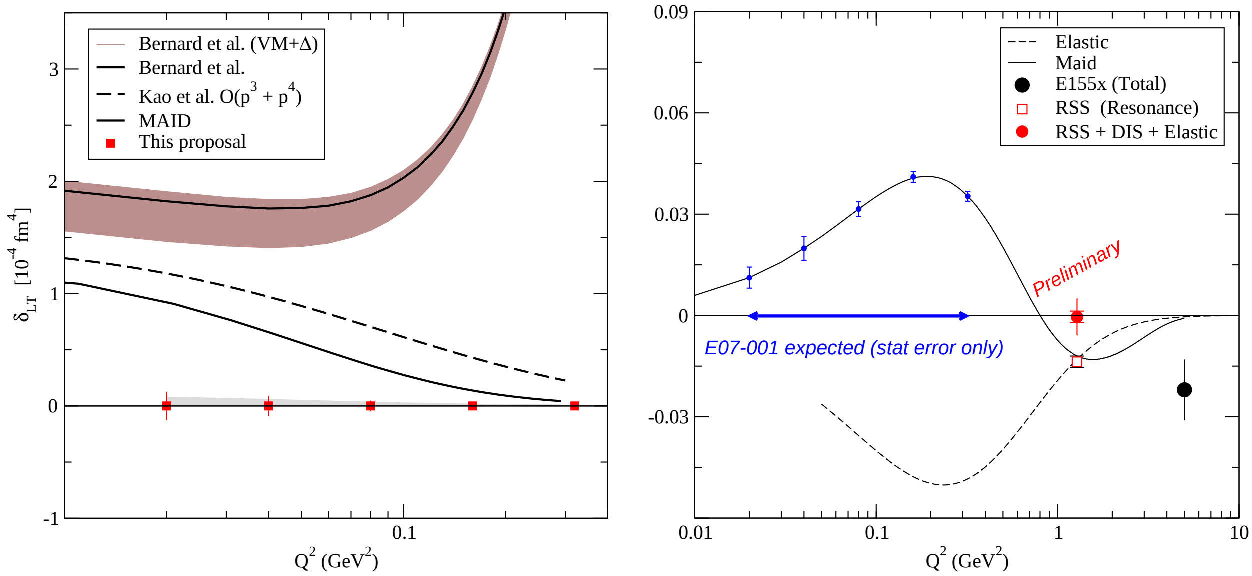

Figure 2: **Left:** Projected results for δ_{LT}. Statistical errors are shown on the symbols. Systematic is represented by the grey band on the axis. χPT predictions from Bernard *et al.* [10], and Kao *et al.* [11]. **Right:** Projected statistical error bars for $\Gamma_2^p(Q^2)$.

is particularly surprising since δ_{LT} is insensitive to the Δ resonance contribution which is not well under control in the χPT calculations. For this reason, it was believed that δ_{LT} should be more suitable than γ_0 to serve as a testing ground for the chiral dynamics of QCD [10, 11]. It is natural to ask if this discrepancy exists in the proton case, and determining the isospin dependence will help to solve this δ_{LT} puzzle.

The generalized longitudinal-transverse polarizability can be extracted from a measurement of the spin structure functions g_1 and g_2:

$$\delta_{LT}(Q^2) \quad = \quad \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\Big[g_1(x,Q^2)+g_2(x,Q^2)\Big]dx. \tag{3}$$

Measurement of g_2 also allows for a test of the Burkhardt-Cottingham (BC) sum rule [7], a “super-convergence relation” that is valid for any value of Q^2:

$$\int_0^1 g_2(x,Q^2)dx = 0, \tag{4}$$

E07-001 [9] has been conditionally approved to run in JLab Hall A. We will perform an inclusive measurement at forward angle of the proton spin-dependent cross sections in order to determine the g_2^p structure function in the resonance region for $0.02 < Q^2 < 0.4$ GeV^2. This measurement will allow an extraction of δ_{LT}, and a test of the BC sum rule.

For this experiment we will install the JLab-UVA polarized ammonia target in Hall A for the first time. This installation will involve significant changes to the existing Hall A beamline in order to properly transport the electron beam in the presence of the 5T magnetic field of the transversely polarized target. Projected results for δ_{LT} and the BC sum rule are shown in Fig 2.

3 RSS: The Resonant Spin Structure Experiment

Experiment E01-006 was conducted in Hall C of the Thomas Jefferson National Accelerator Facility. We measured parallel and perpedicular proton and deuteron asymmetries in the scattering of 100 nA polarized 5.755 GeV electrons. Scattered electrons were detected at an angle of 13.15° using the Hall C High Momentum Spectrometer. Full details of the experiment can be found in Refs. [4] and [5].

The twist-3 matrix element d_2 is related to the higher twist contribution to g_2 via:

$$d_2(Q^2) = 3\int_0^1 x^2 \left[g_2(x,Q^2) - g_2^{\mathtt{WW}}(x,Q^2)\right] dx \tag{5}$$

where $g_2^{\mathtt{WW}}(x,Q^2)$ is the leading twist part of g_2 and is given by the Wandzura-Wilczek [8] relation:

$$g_2^{\mathtt{WW}}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{g_1(y,Q^2)}{y} dy \tag{6}$$

Using 6, we can re–express Eq. 5 as a higher moment of a simple linear combination of the g_1 and g_2 structure functions:

$$d_2(Q^2) = \int_0^1 x^2 \left[2g_1(x,Q^2) + 3g_2(x,Q^2)\right] dx \tag{7}$$

$d_2(Q^2)$ measures the deviation of the g_2 structure function from leading twist behaviour, and as such, it is sensitive to quark-gluon interactions beyond the simple quark parton model. Fig. 3 shows the measured value [4] of $d_2(Q^2 = 1.279)$ in the left panel. Our results are clearly non-zero by several standard deviations.

The right panel displays $\Gamma_2 = \int g_2(x,Q^2)dx$. The RSS resonance region data covers the range $1090 < W < 1910$ MeV, $(0.3161 < x < 0.823)$. To estimate the unmeasured contribution to Γ_2 as $x \to 0$ we assume that the Wandzura-Wilczek [8] relation holds and that

$$\int_0^{x_0} g_2(x,Q^2)dx \simeq \int_0^{x_0} g_2^{\mathtt{WW}}(x,Q^2)dx \tag{8}$$

$$= x_0 \int_{x_0}^1 \frac{g_1(x,Q^2)}{x} dx \tag{9}$$

where Eq. 9 follows from integration by parts. The total integral exhibits a striking cancellation of the inelastic (resonance+DIS) and elastic contributions, leading to satisfaction of the Burkhardt-Cottingham sum rule within uncertainties.

The combination of high precicion proton and deuteron data also allows the extraction of the neutron structure fuctions as shown in Fig. 4.

4 Spin Asymmetries of the Nucleon Experiment

JLab E07-003 is scheduled to run in Hall C for 70 days in 2008. The SANE experiment will perform an inclusive double polarization measurement in order to extract the proton spin structure functions g_1 and g_2 for $0.3 \leq x \leq 0.8$ and $2.5\ \mathrm{GeV}^2 \leq Q^2 \leq 6.5\ \mathrm{GeV}^2$, in a region where the nucleon spin structure remains largely unknown. Higher twists will be investigated via the moments of g_1 and g_2. Expected precision is shown in Fig. 5 and 6.

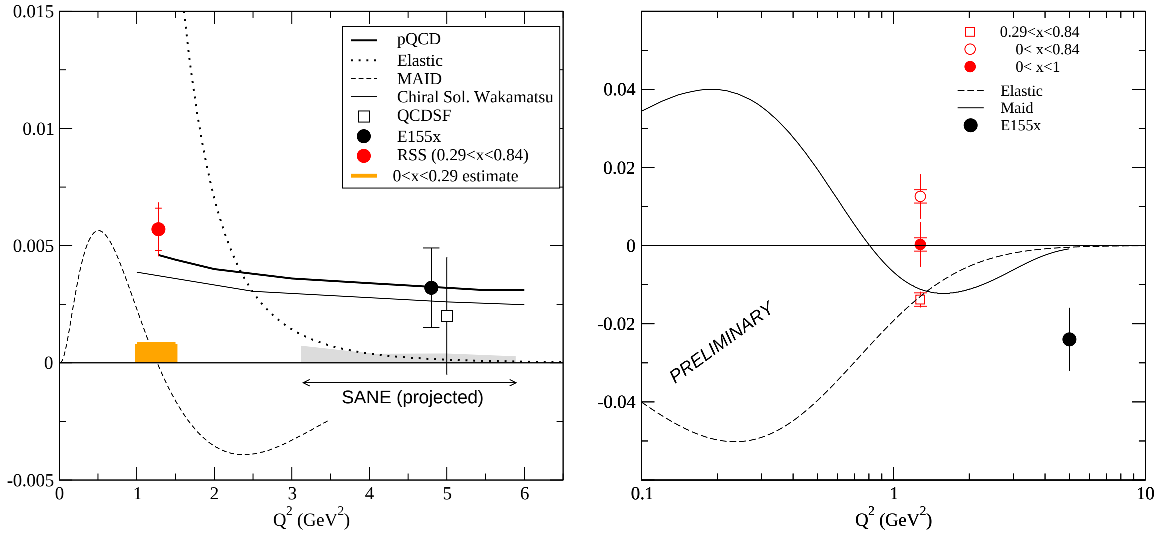

Figure 3: RSS results. **Left:** $\mathrm{d}_2^p(Q^2 = 1.279)$ [4]. **Right:** $\Gamma_2^p(\mathrm{Q}^2)$.

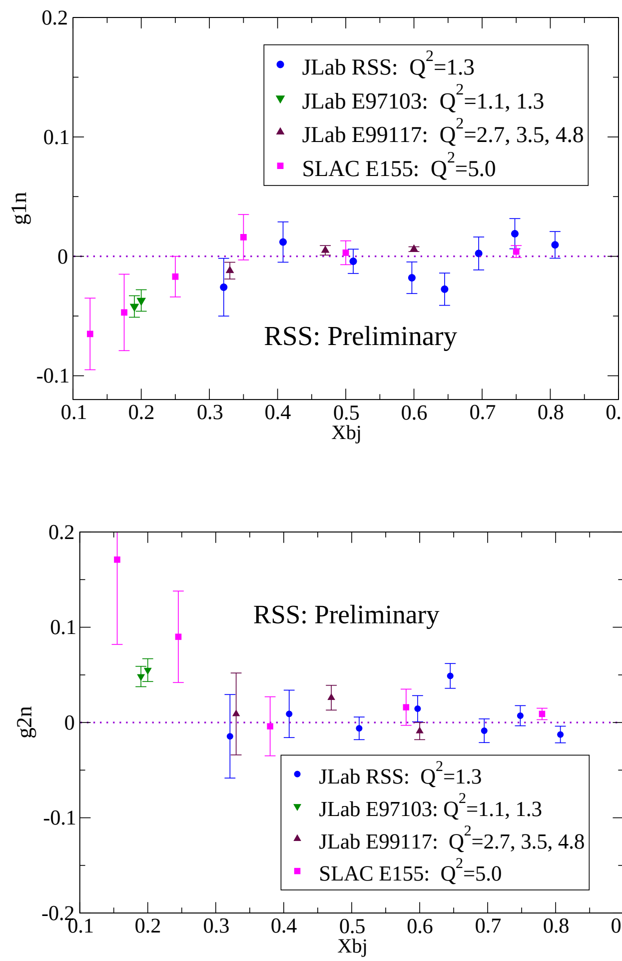

Figure 4: Preliminary RSS Neutron g_1 and g_2 structure functions compared to world data.

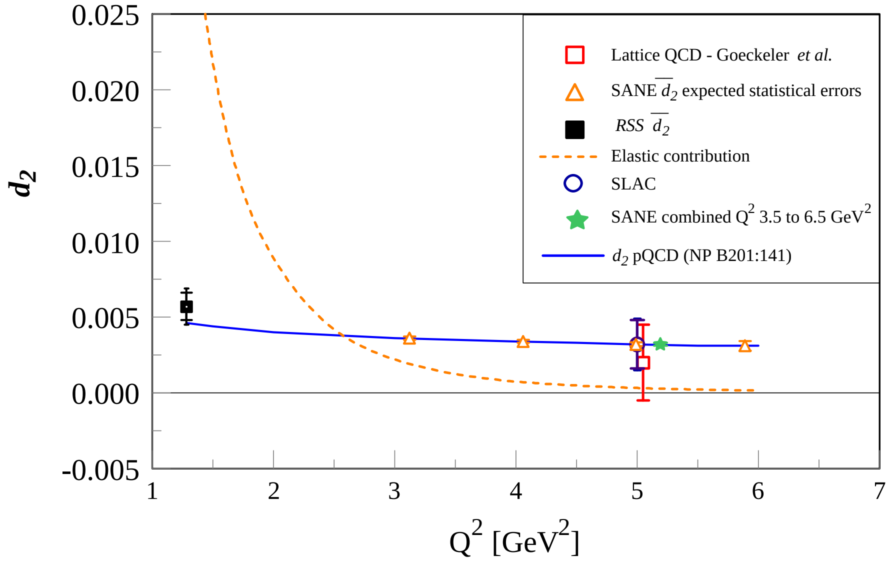

Figure 5: SANE: Projected errors for proton d_2.

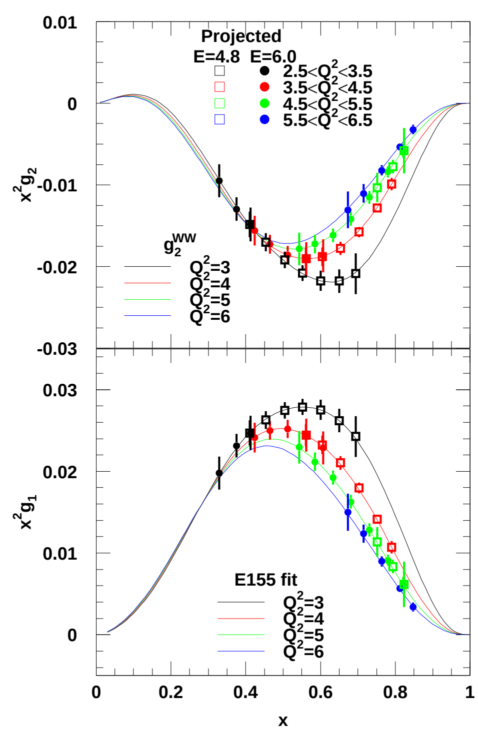

Figure 6: SANE: Projected errors for proton g_1, g_2

5 Summary

We have presented here a small sample of the high quality Jefferson Lab spin program data. For a more general overview, we refer the reader to Ref. [12]. We look forward to many future discoveries and challenges as the JLab 12 GeV upgrade [13] commences.

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